Efficacy of Ultrasound for German Cockroach (Orthoptera: Blattellidae) and Oriental Rat Flea (Siphonoptera: Pulicidae) Control

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ABSTRACT Nine commercially manufactured ultrasound pest control devices were evaluated for acoustical characteristics and for efficacy against German cockroaches, *Blattella germanica* (L.), and oriental rat fleas, *Xenopsylla cheopis* Rothschild. All devices tested produced ultrasound, but the quality of the sound differed for each device. German cockroaches entered ultrasound-treated rooms as readily as they did untreated rooms. Field efficacy testing demonstrated that German cockroach populations were not significantly reduced in ultrasound-treated apartments. Oriental rat fleas were capable of mating, oviposition, larval development, and pupation when reared in ultrasound-treated rooms. Results indicate that manufacturer claims of cockroach and flea control with ultrasound devices cannot be substantiated.

KEY WORDS *Blattella germanica,* ultrasound, *Xenopsylla cheopis,* ultrasound devices

USE OF ULTRASOUND to control insect pests seemed promising especially since ultrasound has been identified as a key factor in certain predator/prey interactions. Commercial ultrasound device manufacturers have cited published literature on the effects of ultrasound on moths and crickets (e.g., Roeder & Treat 1957, Griffin et al. 1960, Roeder 1962, Moiseff et al. 1978) to document the fact that insects avoid ultrasound and that the concept is valid for developing ultrasound devices for control of household pests. However, commercially developed and marketed devices that have been evaluated for control of mosquitoes and cockroaches have failed to provide control by repellency or mortality of the pests (Gorham 1974, Kutz 1974, Rasnitsyn et al. 1974, Schreck et al. 1977, 1984, Ballard & Gold 1982, 1983, Gold et al. 1984). Gold et al. (1984) evaluated four commercially available ultrasonic devices and found that they produced ultrasound; however, their output was less than manufacturer claims. Gold et al. (1984) also concluded that many advertising claims were gross exaggerations. In addition, Schreck et al. (1984) concluded that one of the ultrasound devices they tested exceeded established guidelines for continuous human exposure to sound radiation.

Current literature has only reported laboratory results of unpulsed, monotone ultrasound (Ballard & Gold 1983) or commercially available devices tested in controlled laboratory environments (Gold et al. 1984, Schreck et al. 1984). The manufacturers and some scientists claim that ultrasound efficacy can only be perceived in larger arenas with human habitation. Since ultrasound devices are still available to the general public, we evaluated the ultrasound produced by nine ultrasonic pest control devices and the potential of these devices to control German cockroaches, *Blattella germanica* (L.), and oriental rat fleas, *Xenopsylla cheopis* Rothschild, in room-size arenas and inhabited apartments.

Materials and Methods

Ultrasound Devices. The ultrasonic devices were either purchased from commercial sources, submitted by the manufacturers for evaluation, or provided by individuals who had purchased ultrasonic devices and were curious about whether they worked. The ultrasonic devices evaluated were Pest Sentry Model PS1500 (Sentronic Control, Danville, Va.), Jonfor (Jonfor Systems), Ultra-Shield Model 200 and Model 250B (Intercontinental Development, Houston, Tex.), Scram (Shelburne, Owings Mills, Md.), Florida Ultrasound (Florida Ultra-sonics, Ft. Lauderdale, Fla.), Pied Piper Model 1 and Model 2 (Pied Piper, Largo, Fla.), and Pest Chaser Model PC 100 (SonicTechnology, Grass Valley, Calif.). All devices were in working condition as determined by acoustical testing procedures.

The sound output of the nine devices was evaluated as described by Schreck et al. (1984). The devices were placed inside a commercial anechoic chamber, and sound output measured at a distance of 1.0 m. A Bruel and Kjar (B&K) 4135 condenser

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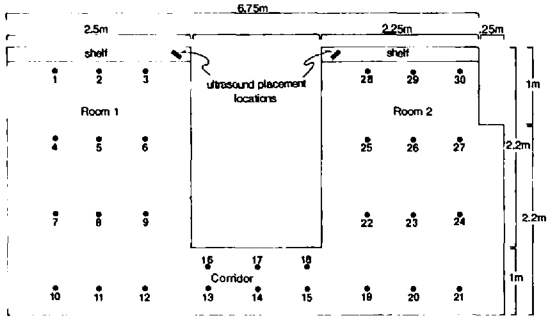

Fig. 1. The floor plan and acoustical monitoring locations in the test rooms. Numbers indicate locations at which sound pressure levels were measured.

microphone with a frequency response of 39 Hz–100 kHz ± 3 dB (0 dB re 20 μPa) was used. The microphone was coupled through a cathode follower to a B&K 2608 sound pressure level meter. The signal was analyzed on a Nicolet 660A dual channel computing FFT Analyzer and plotted on a Tektronic 4662 interactive digital plotter.

German Cockroach. The floor plan of the cockroach testing rooms consisted of two unfurnished rooms connected with a corridor (1 m wide by 2 m long) (Fig. 1). The rooms were caulked to prevent cockroach escape. A band of fluorocarbon (0.5 m) with a band of TakTrap (30 cm) above the fluorocarbon was applied to walls of the room to prevent cockroaches from climbing the walls and escaping. Food (Purina Rodent Chow), water, and harborage (10 by 60 cm rolled cardboard) were placed in the corners of each room. The ultrasound units were placed in room corners on shelves 0.5 m above the floor.

Thirty sound measuring points (Fig. 1) were established to determine the intensity of ultrasound for each device. Points 1–12 were located in Room 1, points 19–30 were in Room 2, and points 13–18 were located in the corridor between the two rooms. Our objective was to create a gradient of sonic treatment so that released cockroaches could choose to enter or leave an ultrasound-treated environment. The mean sound pressure levels (SPL) and 95% CL were calculated for room 1, room 2, and the corridor, and data were analyzed by analysis of variance (ANOVA).

Two types of bioassays were used to determine efficacy—a 24-h test and a 72-h test. In the 24-h test, laboratory-reared Orlando normal cockroaches were released into the corridor between rooms 1 and 2. Fifty cockroaches were placed in each of two glass jars (1 liter) placed on their sides. This permitted normal cockroach movement to exit the jar. After 24 h, most cockroaches had moved to harborages in the test rooms and were collected by shaking them into glass utility jars (4 liter). Numbers of cockroaches removed from room 1, room 2, and between rooms were recorded. In the 72-h test, 50 Orlando normal German cockroaches were released in room 1 and 50 were released in room 2 by the same method described for the 24-h test. After 72 h, the cockroaches were removed from the rooms. Numbers captured in room 1, room 2, or between rooms were recorded.

All room tests with the ultrasound units were run in pairs. The ultrasound device was first placed in room 1 and then in room 2. Two paired tests with each of the nine units were run with the 24- and 72-h protocols. An additional three paired tests of three ultrasound units were run with the 24-h protocol on three ultrasound units. Data were analyzed by Student's *t* test (Snedecor & Cochran 1967).

To determine whether the presence of furniture might affect the treatment of a room with ultrasound, an upholstered chair and sofa and a coffee table were placed in room 1. A Pest Chaser device was placed in room 1, and the SPL was measured at the 30 sound monitoring points. SPL's were analyzed by ANOVA.

Field tests of the Pest Chaser device were accomplished in three-bedroom apartments (94 m^2) at a low income housing complex in Gainesville, Fla. Ten units were treated by placing ultrasound devices in the dining area pointing directly into the kitchen. Ten apartments served as untreated controls. German cockroach populations were

Table 1. Characteristics of commercial ultrasonic units

	No. of speakers	SPL (dB)	Low frequency		High frequency 1			PTI (ms)	High frequency 2			Period (m)
			Hz	Wave-form	kHz	Wave-form	PTD (ms)		kHz	Wave-form	PTD (ms)	
Pest Sentry PS 1500	1	51	60	SW	41[a]	SW	60	—	52[a]	SW	85	145
Jonfor	2	103	—	—	17	SW	438	—	41	SW	320	756
Ultra-Shield 200	1	91	—	—	28	SW	450	—	71	SW	550	1,000
Ultra-Shield 250B	1	91	—	—	24	SW	262	—	61	SW	250	512
Scram	1	59	120	Pulse	42	SW	7.6	—	53	SW	14.2	21.8
Florida Ultra-sound	2	90	60	SW	31	SW	7.8	—	43	SW	5.6	13.4
Pied Piper 1	1	88	60	Pulse	26–48	SW	8.4	—	36	SW	7.9	16.3
Pied Piper 2	2	96	60	SW	23	SW	12.8	—	46	SW	4.5	17.3
Pest Chaser	1	92	—	—	31–44	SW	8.75	6.6	—	—	8.25	17.0

PTD, pulse train duration (ms); PTI, pulse train interval (ms); SW, sine wave.
[a] Measured at the frequency with the greatest amplitude.

Table 2. Mean SPL (dB) in test rooms treated with nine ultrasound devices

Room treatment	$\bar{x}$ SPL (95% CL)	
	Room 1	Room 2
Ultrasound	75.44 (74.42–76.46)	74.89 (73.80–75.98)
Corridor	71.33 (70.63–72.04)	69.64 (69.00–70.28)
Nonultrasound	64.92 (63.98–65.85)	65.38 (65.02–65.73)

Background equipment sensitivity and noise was 63–66 dB.

Table 3. Mean SPL (dB) in furnished and unfurnished test rooms treated with Pest Chaser device

Room treatment	$\bar{x}$ SPL (95% CL)	
	Furnished room	Unfurnished room
Ultrasound	74.10 (73.08–75.11)	79.75 (78.01–81.48)
Corridor	73.00 (71.50–74.49)	75.67 (75.20–76.13)
Nonultrasound	67.25 (66.25–68.25)	71.30 (70.61–71.99)

Background equipment sensitivity and noise was 63–66 dB.

monitored weekly in the treated units by placing one Strike cockroach sticky trap (Zoecon, Dallas, Tex.) under the sink in each for 24 h. Owens & Bennett (1982) found that, although cockroach traps were effective monitoring devices, they were ineffective as control devices. Trapping was conducted 1 week pretreatment and for 10 weeks posttreatment. Additionally, check and treated units were monitored every 4 weeks by placing three Strike cockroach sticky traps at standard locations in each apartment for 24 h. The three locations were under the sink, next to the garbage, and on top of the wall cabinets in the kitchen. Trapping in all 20 apartments was accomplished 1 week pretreatment and 1 and 2 months posttreatment. The field data were analyzed by ANOVA.

Oriental Rat Flea. Efficacy of the ultrasound units for the control of fleas was conducted in the laboratory. Two oriental rat flea colonies were established in the test rooms used for the cockroach experiments. One hundred adult fleas of mixed sexes were placed on caged laboratory rats. The rats were held over flea rearing medium consisting of sand and ground laboratory rat chow. The eggs from the fleas fell on the medium where eclosed larvae fed and pupated in 3 weeks at 28°C. One colony was maintained in a room treated constantly with sound output from the nine ultrasonic pest control devices (alternating devices every 2 days). The other colony was maintained in an untreated room. At 21 days, the media from the two colonies were sifted to remove the flea pupae. All pupae were then counted to determine the flea production within each room.

Results

Results of the acoustical testing of the nine ultrasonic devices are presented in Table 1. The maximum SPL for the units at 1 m was 103 dB for the Jonfor device. The minimum output was 51dB for the Pest Sentry device. All devices tested, except the Pest Sentry, Scram, and Pied Piper Model 1, generated sufficient SPL to be regulated by the Occupational Safety and Health Act for human tolerance of sound radiation (Thurman & Miller 1974). Although these standards apply to occupational tolerance, there are no similar standards for personal or domestic exposure.

Although the devices all had similar claims, the sonic characteristics of the commercial units differed considerably. All devices but the Pest Chaser produced two distinct and alternating high frequency sound outputs. These high frequency outputs ranged from 17 to 71 kHz. The wide variety of output indicates that manufacturers used no commonality of design to produce ultrasound. In addition, all but the Jonfor, Ultrashield 200, Ultrashield 250B, and Pest Chaser units provided a low frequency sound to alert the owner that the device was operational.

Measurements of SPL were compiled for all tested ultrasound devices; means are presented in Table 2. A gradient of loudness was evident with significantly higher SPL in the treated room and lower SPL in the corridor and untreated room (F = 231; df = 2; $P > 0.0001$). Background noise in the room and the acoustical equipment was 64–67 dB. Thus, the mean sound intensity in the untreated rooms was mostly due to background noise. To compare the equivalency of ultrasound device placement in either room 1 or 2, the mean SPL in the ultrasound-treated rooms, the corridor, or the untreated rooms are also presented in Table 2. No significant differences in sound intensity were evident (F = 1.08; df = 1; $P > 0.30$), and the two ultrasound-treated rooms compared favorably with means of 75.44 and 74.89 dB. Thus, cockroaches responding to ultrasound could move along a gradient to areas with less ultrasound, and the paired test protocol would negate any physical differences between rooms since they were acoustically similar.

The addition of furniture to a test room treated with a Pest Chaser device reduced the SPL by up to 20 dB at certain monitoring points. Table 3 indicates that furnishing a room significantly reduced SPL in a treated room by a mean of 5.65 dB (F = 21.62; df = 1; $P > 0.0001$). In addition,

Table 4. German cockroach response to nine commercial ultrasound devices in room tests

Test protocol (h)	No. ± SE of cockroaches found in:		
	Ultrasound room	Corridor	Untreated room
24	45.5 ± 5.6	13.7	40.8 ± 3.9
72	47.7 ± 9.1	5.3	47.0 ± 9.2

Differences in numbers between rooms not significant as determined by Student's t test (Snedecor & Cochran 1967) for 24-h data (t = 0.68; df = 23; $P \geq 0.49$) and 72-h data (t = 0.02; df = 17; $P \geq 0.98$).

Table 5. Mean number of German cockroaches trapped in Pest Chaser device and check apartments

Months	$\bar{x}$ no./trap	
	Ultrasound	Control
0	38.4 ± 11.3	35.2 ± 6.9
1	30.0 ± 7.9	37.2 ± 7.7
2	46.0 ± 8.8	31.9 ± 7.8

Treatments not significantly different as determined by ANOVA ($F = 0.60$; df = 1; $P \geq 0.60$).

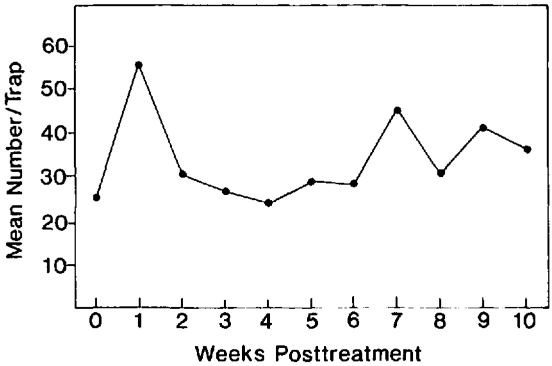

Fig. 2. Mean number of German cockroaches trapped in ultrasound-treated apartments.

SPL measured in the corridor and the untreated room were significantly reduced by 2.67 and 4.05 dB, respectively. Since most inhabited areas of buildings where household pests are prevalent have furniture, the attenuation of sound by placement of furniture indicates that thorough treatment with high SPL is most probably impossible with currently available technology.

The results presented in Table 4, however, indicate that cockroaches did not move predominantly to untreated rooms where the sound intensity was significantly lower. In fact, during the 24-h study, a numerically greater percentage (45.5%) of cockroaches was found in the ultrasound-treated rooms compared with the untreated rooms (40.8%). No significant difference in the movement of German cockroaches into treated or untreated rooms was observed, and no mortality of cockroaches was observed in any of the room tests. These results indicated that cockroaches were just as likely to enter a room treated with ultrasound as a similar untreated room. The 72-h tests also indicate that cockroaches are not repelled from rooms treated with ultrasound within a 3-day period.

The results of field testing the Pest Chaser device are presented in Fig. 2 and Table 5. The weekly mean number of German cockroaches did not decline significantly during the 10-week treatment interval. In fact, the mean trap catch increased from 25.10 German cockroaches pretreatment to 46.80 at week 7 posttreatment (Fig. 2). At that point, the residents were complaining severely about the lack of control. The increased mean trap catch of 56.30 at week 1 posttreatment was due to one heavy trap catch of 456. This increased trap catch at week 1 of the test may be due partially to the increased movement of German cockroaches after initial placement of ultrasonic devices as observed by Gold et al. (1984).

The monthly trap catches of German cockroaches (Table 5) indicated that the German cockroach populations were not significantly reduced by the presence of the ultrasound devices. At the 2-month posttreatment count, the mean trap catch increased from 38.4 pretreatment to 46.0. Meanwhile, the check apartment trap catches had declined from 35.2 pretreatment to 31.9.

By 10 weeks posttreatment, residents were completely dissatisfied by the performance of the devices and requested that they be removed. Three devices were placed in plastic, sealed, and returned to the laboratory. A total of eight German cockroach nymphs were found in the plastic bags after 24 h. Their presence indicated that the ultrasound devices were being utilized as harborages and did not effectively repel the cockroaches.

The numbers of oriental rat fleas produced in the ultrasound-treated and the untreated room were 13,104 and 15,561 flea pupae, respectively. The test was not replicated, and it is impossible to say whether the flea production was significantly lower in the ultrasound-treated room. However, the large number of fleas produced in ultrasound-treated rooms does indicate that ultrasound is probably not a reliably effective method of flea control. It does not prevent flea mating, oviposition, larval development, or pupation.

Discussion

From these studies of ultrasonic pest control devices, we conclude that manufacturer claims of efficacy are unfounded. Although moths have evolved tympanic organs to detect the ultrasonic frequencies generated by bats (Roeder & Treat 1957), household insects such as German cockroaches and fleas have not been subjected to the same evolutionary pressures. As a consequence, German cockroaches did not avoid entry into rooms treated with ultrasound. German cockroaches in established infestations did not leave rooms due to ultrasound treatment, as evidenced in our 24- and 72-h protocols. No German cockroach mortality was attributable to the ultrasound treatments. In the field tests, German cockroaches were as prevalent after 10 weeks of treatment in ultrasound-treated apartments as in the control apartments. In fact, their numerical increase was most probably the result of the tenant discontinuing use of pesticides. Oriental rat fleas could reproduce, oviposit, develop through the larval stage, and pupate normally in ultrasound-treated environments. Although manufacturers claim that ultrasound can

penetrate voids to control pests, the presence of furniture in a room significantly decreased the intensity of ultrasound. Therefore, the physics of ultrasound limits its potential efficacy in normal residences and commercial establishments.

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